PROCEDURE FOR MAKING VOLTAGE DROP STUDIES

by

Bruce O. Watkins, Engineer
Max W. Rothpletz, Associate Engineer

Technical Standards Division

U. S. DEPARTMENT OF AGRICULTURE
RURAL ELECTRIFICATION ADMINISTRATION
TECHNICAL STANDARDS DIVISION

Technical Standards Bulletin #11
December 17, 1943

C-196

SUMMARY

This bulletin contains a procedure for preparing voltage drop studies of rural lines.

The authors wish to express their appreciation for the assistance rendered by numerous engineers who provided information and offered suggestions for the improvement of this bulletin, particularly Mr. Lee M. Moore, Head, Consumers Service Section, who collaborated with the authors in preparing "Basic Data for Rural System Design" from which the peak demand curves used in this bulletin were obtained.

PROCEDURE FOR MAKING VOLTAGE DROP STUDIES

In accordance with the provisions of the Line Construction Engineering Service contract (Form DS-55, 1/1/42), project engineers are required to submit with the Plans and Specifications a voltage regulation study for each conductor group to be included in the contractor's proposal. For the sake of uniformity of records it is requested that these studies be submitted in accordance with the procedure outlined in this bulletin, which supersedes the procedure contained in Engineering Memorandum 33R.

The previous instructions on voltage regulation (Engineering Memorandum 33R) outlined a procedure for calculating voltage rise due to the high ratio of capacitance to inductance on lightly loaded lines. Since this light load condition, which is sometimes present on newly constructed lines, is of relatively short duration and has practically disappeared from REA systems, it was considered advisable to omit reference to voltage rise calculations in this bulletin.

A number of revisions have been made in the procedure as well as in the data on which the study is based. The peak demand curves have been revised on the basis of a study of the peak kilowatt demands of over 300 rural systems and have been reproduced on log-log paper to limit the number of pages necessary for their presentation.

The sheet (Form TS-11) for calculating and tabulating the results has also been revised. This was done to simplify the procedure and to provide for the inclusion of calculation of voltage drops due to concentrated loads.

The wire factor tables have been extended to include additional sizes of copper equivalent conductor as well as two sizes of steel conductor with a 10 ampere load current. The table also includes factors for 80 as well as 90 percent power factors. For those who are interested in the calculation of wire factors, the formula is explained in an addendum in the latter pages of this bulletin.

A sample problem together with its solution is included in this bulletin to demonstrate the described procedure. It is recommended that these sample calculations be carefully followed and fully understood before any actual computations are attempted.

INSTRUCTIONS FOR MAKING A VOLTAGE DROP STUDY

(NOTE: These instructions supersede those of July 23, 1940.)

INFORMATION REQUIRED:

As a basis for the preparation of a voltage drop study of a rural power distribution system, the following information relative to that system should be on hand.

1. A key map or load diagram of the system showing the primary distribution lines' wire size, phasing and location of concentrated loads. Although no provision is made for directly incorporating this information in the study, any areas which may reasonably be served by the system at some future date should be indicated on the key map. This will give an indication of whether or not any calculated voltage drops are excessive in the light of possible future line extensions.

2. The number of signed and potential (unsigned) consumers on each section of the system. These sections are to be determined in accordance with the "Procedure" on page 5. When consumers are very unevenly distributed, their locations should be shown on the map.

3. The average monthly kilowatt-hour consumption per consumer may be estimated from a knowledge of local conditions or from actual operating records for the area.

4. The size, number of phases, and location of any substantially large concentrated load.

5. The approximate power factor of the distributed load and of the concentrated loads should be known or may be assumed on a rational basis.

ASSUMPTIONS ON WHICH STUDY IS BASED:

1. Service is to be provided to all the signed consumers and fifty percent of the potential (unsigned) consumers. The percentage of potential consumers may be changed by the project engineer with the approval of REA if local conditions warrant such a change.

2. The voltage drop in each section is the same as that which would exist if one-half of the load in the section being considered and all of the load beyond this section were concentrated at the end of the section away from the source of supply. This assumption avoids the necessity of calculating a load-center for each section and does not introduce appreciable error unless the load in the section is very unevenly distributed.

3. The loads on all three-phase lines are assumed to be balanced between phases.

Form TS-1

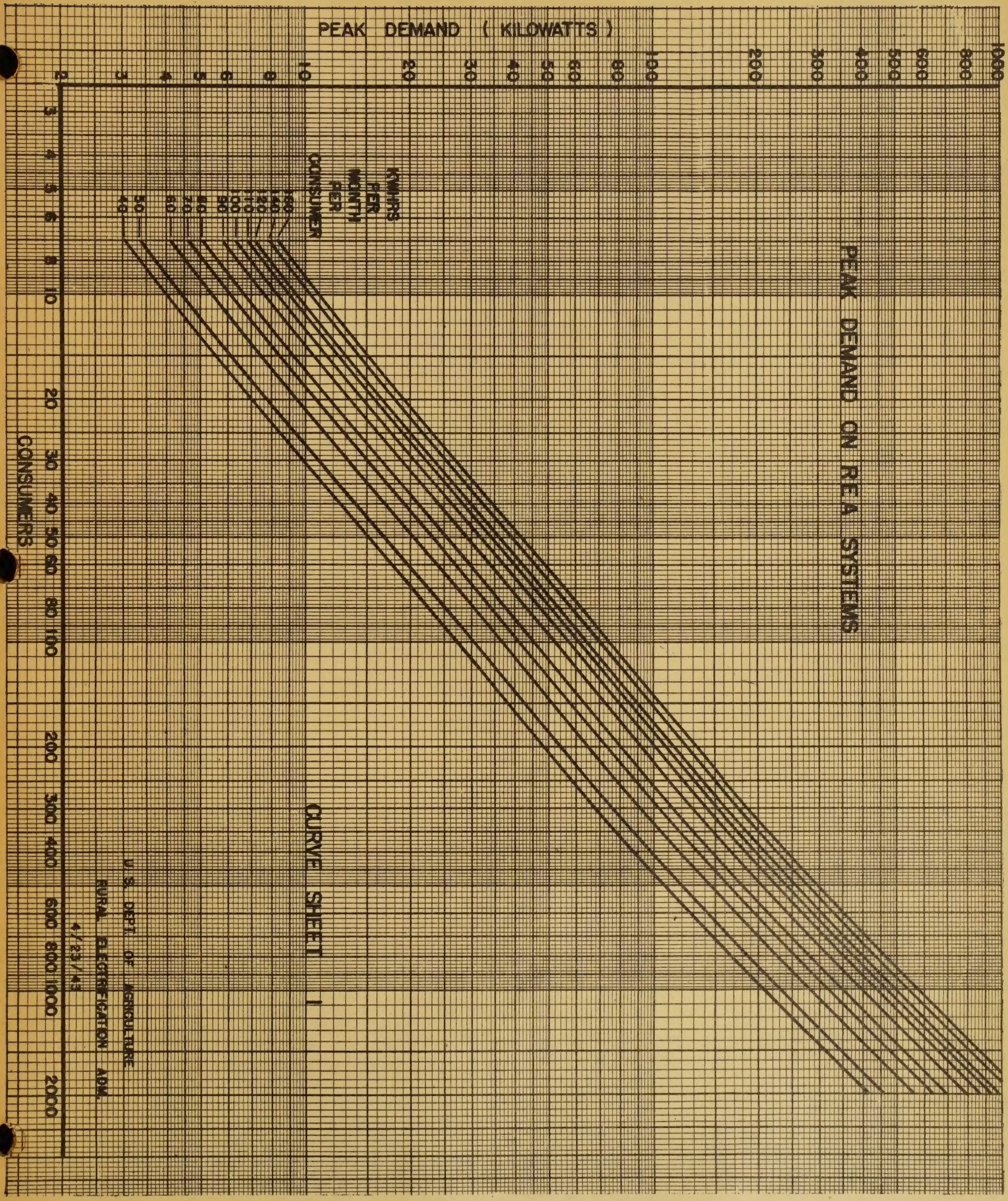
U. S. DEPT. OF AGRICULTURE

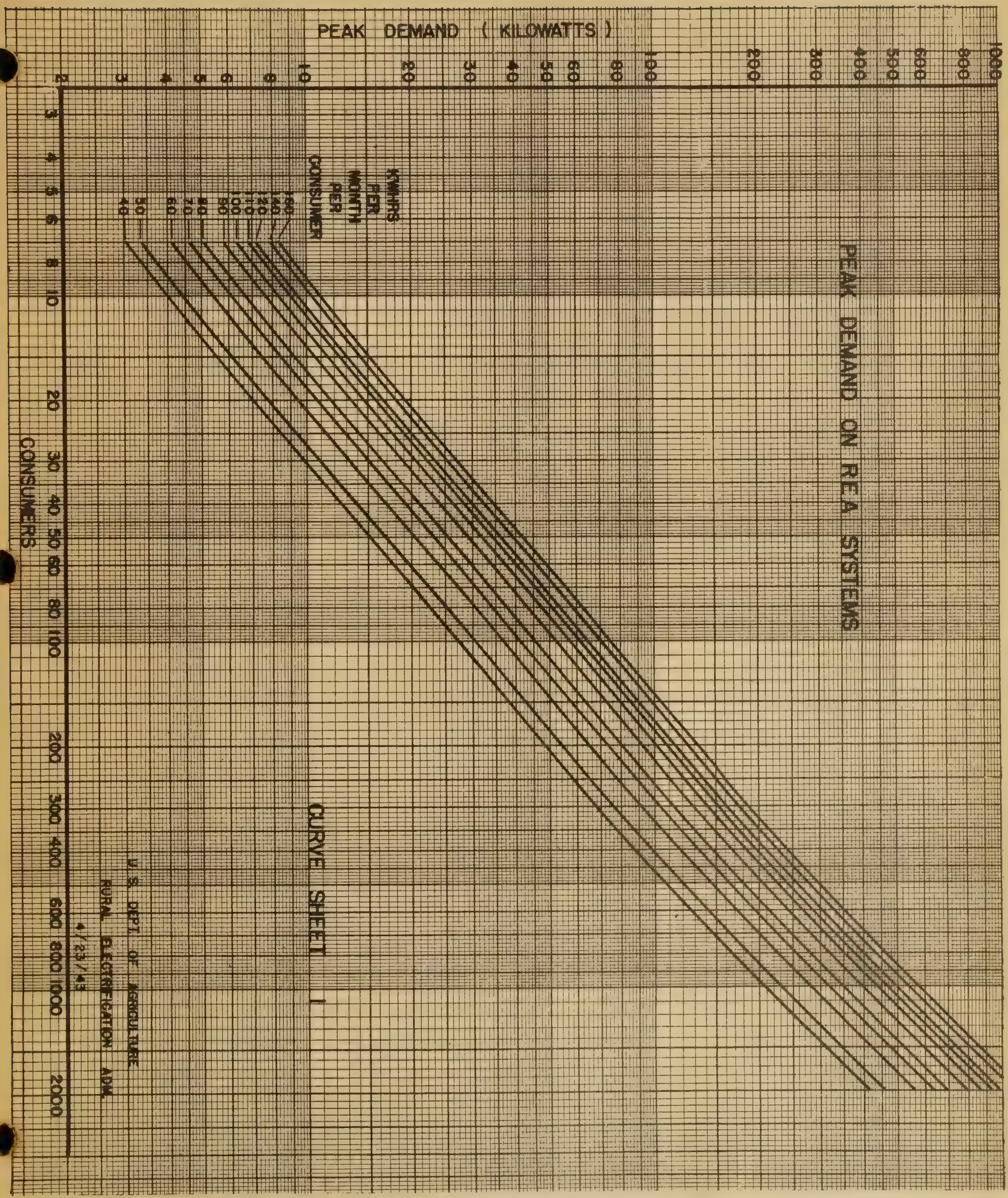
RURAL
ELECTRIFICATION
ADMINISTRATION

VOLTAGE REGULATION SHEET

Project .... Sheet .... of ...... sheets
Submitted by .... Date ....
Checked by .... Date ....

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
SECTION	NUMBER OF CONSUMERS					KWH PER MONTH	KW PEAK	LENGTH OF SECTION IN MILES	KW MILES	CON-DUCTOR SIZE CU. EQUIV.	ø / KV	WIRE FACTOR	% VOLTAGE DROP				
	SIGNED	PO-TEN-TIAL	ULTI-MATE	BEYOND THIS SECTION	EQUIVA-LENT THIS SECTION								THIS SECTION			TOTAL	AT POINT
													CONCEN-TRATED LOAD	DISTRI-BUTED LOAD	SUM		


PEAK DEMAND ON R E A SYSTEMS
PEAK DEMAND (KILOWATTS)
CONSUMERS
KWHRS PER MONTH PER CONSUMER
160
140
120
110
100
90
80
70
60
50
40
CURVE SHEET 1
U. S. DEPT. OF AGRICULTURE
RURAL ELECTRIFICATION ADM.
4/23/43


PEAK DEMAND ON R.E.A SYSTEMS
PEAK DEMAND (KILOWATTS)
2
3
4
5
6
8
10
20
30
40
50
60
80
100
200
300
400
500
600
800
1000
KWHRS PER MONTH PER CONSUMER
160
140
120
110
100
90
80
70
60
50
40
CONSUMERS
3
4
5
6
8
10
20
30
40
50
60
80
100
200
300
400
600
800
1000
2000
CURVE SHEET I
U. S. DEPT. OF AGRICULTURE
RURAL ELECTRIFICATION ADM.

W I R E   F A C T O R   T A B L E

FOR MULTI-GROUNDED NEUTRAL LINES ONLY

U. S. Department of Agriculture	July 10, 1943	Rural Electrification Administration

SINGLE-PHASE 4 FT. SPACING

Conductor \ Voltage L-G	90% P.F. (LAG) 2400	4800	6900	7200	7620	12000	13200	80% P.F. (LAG) 2400	4800	6900	7200	7620	12000	13200
#1 Cu. Equiv.	27.2	6.79	3.30	3.02	2.70	1.09	0.900	33.0	8.21	3.98	3.66	3.26	1.32	1.09
2 " "	32.0	7.98	3.87	3.55	3.17	1.28	1.06	38.0	9.50	4.61	4.23	3.78	1.52	1.26
4 " "	43.5	10.9	5.26	4.83	4.32	1.74	1.43	50.2	12.5	6.07	5.56	4.97	2.00	1.67
6 " "	60.3	15.1	7.29	6.70	5.98	2.41	1.99	67.5	16.9	8.19	7.50	6.70	2.70	2.24
8 " "	85.8	21.4	10.4	9.54	8.53	3.43	2.84	93.5	23.4	11.4	10.4	9.27	3.74	3.10
9½ " "	111.0	27.7	13.4	12.3	11.0	4.43	3.67	119.	30.0	14.5	13.3	11.8	4.78	3.96
11 " "	155.0	38.7	18.8	17.2	15.4	6.20	5.13	165.	41.1	19.9	18.4	16.4	6.60	5.46
Steel (3 strand @ 10 amps)														
4	192.0	48.1	23.2	21.3	19.0	7.70	6.36	205.	51.0	24.8	22.7	20.4	8.19	6.77
6	244.0	61.0	29.6	27.1	24.2	9.76	8.05	256.	64.0	31.0	28.4	25.4	10.3	8.48

THREE-PHASE 4.69 FT. SPACING

Conductor \ Voltage L-G / L-L	90% P.F. (LAG) 2400 / 4160	4800 / 8300	6900 / 11950	7200 / 12450	7620 / 13150	12000 / 20800	13200 / 22850	80% P.F. (LAG) 2400 / 4160	4800 / 8300	6900 / 11950	7200 / 12450	7620 / 13150	12000 / 20800	13200 / 22850
#2/0 Cu. Equiv.	4.73	1.18	0.572	0.525	0.469	0.189	0.156	5.88	1.47	0.710	0.652	0.583	0.235	0.195
0 " "	5.52	1.38	0.667	0.613	0.547	0.221	0.183	6.63	1.66	0.802	0.737	0.658	0.265	0.219
1 " "	6.44	1.61	0.779	0.715	0.638	0.258	0.213	7.63	1.91	0.923	0.848	0.757	0.305	0.252
2 " "	7.54	1.89	0.913	0.838	0.748	0.302	0.250	8.75	2.19	1.06	0.972	0.869	0.355	0.288
4 " "	10.8	2.70	1.31	1.20	1.07	0.432	0.358	11.7	3.00	1.45	1.33	1.19	0.478	0.395
6 " "	15.9	3.98	1.92	1.76	1.57	0.634	0.525	17.1	4.28	2.07	1.90	1.70	0.684	0.564
8 " "	24.0	5.98	2.90	2.66	2.37	0.958	0.791	25.3	6.32	3.06	2.81	2.51	1.01	0.835
9½ " "	32.0	8.06	3.87	3.55	3.17	1.28	1.06	33.5	8.38	4.05	3.72	3.32	1.34	1.10
11 " "	46.2	11.5	5.59	5.13	4.58	1.85	1.53	47.7	11.9	5.77	5.30	4.74	1.90	1.58
Steel (3 strand @ 10 amps)														
4	57.8	14.4	7.00	6.42	5.73	2.31	1.91	60.4	15.1	7.31	6.71	5.99	2.41	2.00
6	74.6	18.5	8.99	8.24	7.35	2.97	2.46	76.7	19.2	9.28	8.53	7.64	3.08	2.54

NOTES:

1. These factors are based on values calculated at 25°C, with ground resistivity = 100 meter ohms.
2. A factor has been added to account for ground contact resistance.
3. To obtain wire factors for voltages not shown, assume that the wire factor varies inversely as the square of the voltage.
4. For sections of "V" phase, use one-half the corresponding single-phase wire factor.
5. For single phase lines connected to delta circuits, or with ungrounded neutral, use two times the three phase value, with proper line-to-line voltage.
6. Formula: Percent drop in section = $\frac{\text{peak kilowatts} \times \text{length in miles}}{1000}$ x wire factor.

4. This study is based on the use of "wire factors" with the sending end voltage applied to the source end of each section of line considered. Since the actual voltage at each point in the system is generally less than the sending end voltage, the voltage drops calculated by this method are not entirely accurate. In addition, a maximum voltage drop of eight percent is assumed on the system. The nearer the actual voltage drop is to this assumed value, the smaller is the error introduced. The total errors introduced by these two assumptions, which greatly simplify the calculations, will in general be quite small, but the procedure should not be regarded as exact.

PROCEDURE:

The first step is to divide the system into sections and assign letters or numbers to the ends of the sections so that reference may be made to any particular section by the letters appearing at its ends. The letters should be placed on the map. The sections should be chosen so as to meet the following requirements:

1. Each section should have the same wire size throughout its length.

2. Sections should start or end at points where there is a change in the number of phases.

3. Sections should be taken so that main junction points or points where long single-phase taps are taken off the main line are at the end of a section.

4. The consumers in any section should be relatively evenly distributed throughout the section.

5. Concentrated loads (particularly large power loads) should appear at the ends of the sections.

After dividing the system into sections in accordance with the foregoing instructions, Form TS-11 may be used for calculating the percent voltage drop at the end of each section.

INSTRUCTIONS FOR COMPLETING FORM TS-11

These instructions are given for the individual columns in the order in which they appear on the form, which is the order in which they should be completed. It is recommended that persons unfamiliar with this form follow through the entire form horizontally for each section. After the procedure has been mastered, considerable time may be saved by completing certain columns vertically before proceeding with the others.

Column (1). Starting at the farthest ends of the system from the substation, designate the section being considered by letters corresponding to the points previously marked on the map to indicate the ends of the sections. Thus A-C designates the section of line between points A and C.

Column (2). In this column show the total number of signed consumers in the section.

Column (3). Show here the number of potential (unsigned) consumers in the section.

Column (4). Insert here the sum of the signed consumers and one-half the unsigned, or potential, consumers (Column (2) plus one-half of Column (3)). This is in accordance with our first assumption that service is to be provided to the signed and fifty percent of the unsigned prospective consumers.

Column (5). This column shows the number of ultimate consumers who are to be supplied power which must flow all the way through the section being considered. These figures are obtained by adding the figures in Column (4) which pertain to sections beyond the section being considered.

Column (6). This column shows the equivalent number of consumers who are supplied through the section being considered. These figures are obtained by adding one-half the ultimate (Column 4) to the number of consumers beyond this section (Column 5).

Column (7). This is the average kilowatt-hour consumption per month and is either obtained from operating reports in the case of energized systems or may be estimated on the basis of a knowledge of local conditions.

Column (8). The peak kilowatt demand for the number of consumers shown in Column (6) (or the peak kilowatt demand for a concentrated, large power, load) is entered in this column. For a distributed load the peak kilowatt demand is read directly from curve sheet No. 1 for the number of consumers shown in Column (6) and the kilowatt-hour consumption shown in Column (7).

Column (9). Show here the total length, in miles, of the section being considered.

Column (10). The kilowatt-miles which is the product of the figures in Column (8) and Column (9) is entered in this column.

Column (11). The conductor size used in the section is noted in this column and is copper equivalent unless otherwise noted on the form.

Column (12). Indicate here the number of phases in the section of line under consideration and the line to ground kilovolts.

Column (13). These values are taken from the table of wire-factors for the conductor size, number of phases, and voltage given in Column (11) and (12). It should be noted that these factors apply only to multi-grounded systems constructed in accordance with REA specifications. Note that for "V" phase lines the wire factor is one-half that of the single phase wire factor.

Column (14). In this procedure the percent voltage drops caused by concentrated power loads are considered separately for each section. This column is used for tabulating that portion of the percent voltage drop in the section due to a large power load beyond the section. The values are obtained by applying the equation, percent voltage drop = $\frac{\text{(kw-miles) x (wire factor)}}{1,000}$, to the values in columns (10) and (13).

Column (15). The percent voltage drop in the section due to distributed load is entered in this column. These values are also obtained by applying the above equation to the values in Columns (10) and (13).

Column (16). For sections in which the voltage drop is partially caused by concentrated (large power) loads and partially by distributed loads, the total drop in the section is shown in this column.

Column (17). These figures show the percent voltage drop at the far end of each section. They are found by starting with the section nearest to the source and summing up the voltage drops in all the sections between the source and the section being considered including the voltage drop in the section being considered. The voltage drops thus calculated therefore apply at the far ends of the sections considered. The percent voltage drop calculated by this procedure is the ratio of the voltage drop to the source voltage expressed in percent.

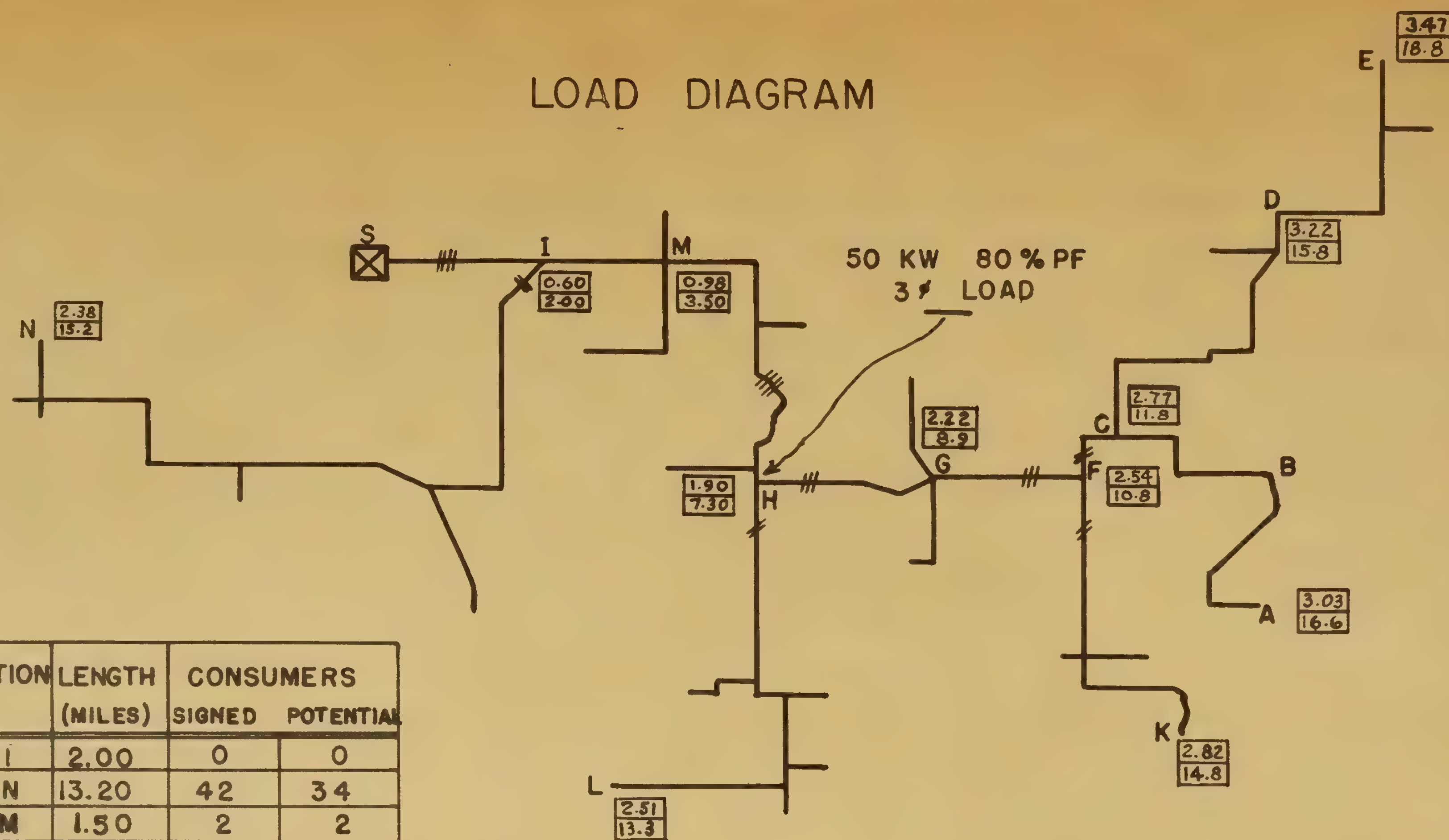
Column (18). This column shows the point at which the calculated voltage drop applies. The letters designate the far ends of the respective sections of Column (1).

SAMPLE VOLTAGE DROP COMPUTATION

Before attempting to prepare a voltage regulation study of any actual system, the following example should be followed through and be thoroughly understood.

On the load diagram for Somestate 14 Jones which is submitted in lieu of a key map, data are given for preparing a voltage drop study. The consumers are assumed to be evenly distributed throughout the sections except that a concentrated load is supplied at point H. In addition, the average kilowatt-hours used per month is approximately one hundred at ninety percent power factor, and the line to ground voltage on the system is 7,200 volts.

LOAD DIAGRAM



SECTION	LENGTH (MILES)	CONSUMERS SIGNED	CONSUMERS POTENTIAL
S — I	2.00	0	0
I — N	13.20	42	34
I — M	1.50	2	2
At M		6	3
M — H	3.80	12	8
H — L	6.00	33	18
H — G	1.60	3	2
At G		13	3
G — F	1.90	5	2
F — K	4.00	23	8
F — C	1.00	3	2
C — A	4.80	16	7
C — D	4.00	15	5
D — E	3.00	12	6

LEGEND

$\boxed{\begin{array}{c}2.54\\10.8\end{array}}$ UPPER FIGURE IS % VOLTAGE DROP AT FULL LOAD FROM SOURCE TO POINT.

LOWER FIGURE IS DISTANCE FROM SOURCE ALONG CIRCUIT IN MILES.

WIRE SIZE: SECTION D—E NO. 9 1/2
ALL OTHER NO. 6

—PROJECT—
SOMESTATE 14 JONES

JOHN DOE
ENGINEER

DATE: JUNE 2, 1943

Form TS-11

U. S. DEPT. OF AGRICULTURE
RURAL
ELECTRIFICATION
ADMINISTRATION

VOLTAGE REGULATION SHEET

Project Somestate – 14 Jones Sheet 1 of 1 sheets
Submitted by John Doe Date July 12, 1943
Checked by Date

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
	NUMBER OF CONSUMERS												% VOLTAGE DROP				
													THIS SECTION				
SECTION	SIGNED	PO-TEN-TIAL	ULTI-MATE	BEYOND THIS SECTION	EQUIVA-LENT THIS SECTION	KWH PER MONTH	KW PEAK	LENGTH OF SECTION IN MILES	KW MILES	CON-DUCTOR SIZE CU. EQUIV.	Ø / KV	WIRE FACTOR	CONCEN-TRATED LOAD	DISTRIB-UTED LOAD	SUM	TOTAL	AT POINT
C–A	16	7	19.5	0	9.75	100	8.0	4.8	38.4	6	1 / 7.2	6.70		0.257		3 027	A
D–E	12	6	15.0	0	7.50	100	6.7	3.0	20.1	9½	1 / 7.2	12.30		0.247		3.470	E
C–D	15	5	17.5	15.0	23.75	100	16.9	4.0	67.6	6	1 / 7.2	6.70		0.453		3.223	D
F–C	3	2	4.0	52.0	54.00	100	34.0	1.0	34.0	6	1 / 7.2	6.70		0.228		2.770	C
F–K	23	8	27.0	0	13.50	100	10.5	4.0	42.0	6	1 / 7.2	6.70		0.282		2.824	K
G–F	5	2	6.0	83.0	86.00	100	50.5	1.9	96.0	6	"V" / 7.2	3.35		0.322		2.542	F
At G	13	3	14.5														
H–G	3	2	4.0	103.5	105.50	100	60.0	1.5	96.0	6	"V" / 7.2	3.35		0.322		2.220	G
H–L	33	18	42.0	0	21.00	100	15.2	6.0	91.2	6	1 / 7.2	6.70		0.611		2.509	L
At H	Concentrated load 3 Ø @ 80% P.F.						50.0										
M–H	For concentrated load at Point H						50.0	3.8	190.0	6	3 / 7.2	1.90	0.361				
M–H	12	8	16.0	149.5	157.50	100	83.0	3.8	315.0	6	3 / 7.2	1.76		0.555	0.916	1.898	H
At M	6	3	7.5														
I–M	For concentrated load at Point H						50.0	1.5	75.0	6	3 / 7.2	1.90	0.142				
I–M	2	2	3.0	173.0	174.50	100	90.0	1.5	135.0	6	3 / 7.2	1.76		0.238	0.380	0.982	M
I–N	42	34	59.0	0	29.50	100	20.2	13.2	266.0	6	1 / 7.2	6.70		1.783		2.385	N
S–I	For concentrated load at Point H						50.0	2.0	100.0	6	3 / 7.2	1.90	0.190				
S–I	0	0	0.0	235.0	235.00	100	117.0	2.0	234.0	6	3 / 7.2	1.76		0.412	0.602	0.602	I
On Sub.				235.0												0	Sub

The first section considered is C-A. From the tabulation on the load diagram, the signed consumers (Column (2)) equals sixteen, and the potential consumers (Column (3)) equals seven. Since the ultimate consumers (Column (4)) equals the signed plus one-half the potential consumers, the ultimate number is 19.5. There are no consumers beyond this section, so that the equivalent consumers in the section equal one-half the ultimate, or 9.75. The kilowatt peak, eight, is read direct from curve sheet #1 for 9.75 consumers on the curve for 100 kilowatt-hours per month. The product of eight kilowatts and 4.8 miles is 38.4 kilowatt-miles in Column (10). The wire factor, 6.70, in Column (13), is obtained from the wire factor table for a single phase line, with #6 copper equivalent conductor, 90% power factor and 7,200 volts line-to-ground. Combining Columns (10) and (13) in the formula for percent voltage drop gives a value of 0.257 for Column (15) as the percent drop in Section C-A.

The above procedure is the same for Section D-E. Section C-D, however, involves distributed load beyond the section and consequently the procedure for Columns (5) through (8) is slightly different. The number of consumers in Column (5) is the sum of the consumers beyond the section which in this instance is fifteen. The equivalent consumers supplied through this section is equal to fifteen (Column (5)) plus one-half of 17.5 (Column 4) = 23.75. The peak kilowatt load (Column 8) is then found from Curve Sheet #1 for 23.75 consumers and the curve for 100 kilowatt-hours per month. The procedure for filling in the remaining columns is the same as previously discussed.

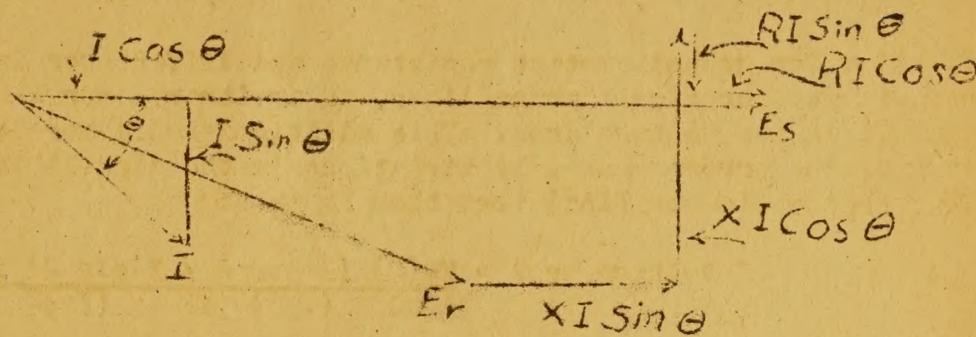
For the concentrated load at point H the procedure is slightly different but is calculated separately for each section as, for instance, section M-H. The type of load is indicated in Columns (2) through (7). Column (8) shows the peak kilowatt load concentrated at point H as given on the Load Diagram. Columns (9), (10), (11) and (12) are completed with the same considerations as previously mentioned. The wire factor, 1.90, is found on the wire factor table for a three-phase load, with #6 conductor, 80% power factor, and 7,200/12,450 volts. The voltage drop due to the concentrated load is noted as 0.361 in Column (14). The same procedure is followed for each section through which the concentrated load is supplied.

To find the total cumulative drop at each point, start with the drops (from concentrated and distributed loads) in section S-1 for point I, and add the drops in each section successively to the far ends of the lines.

ADDENDUM

COMPUTATION OF WIRE FACTORS

For known sending end conditions and lagging power factor, the vector diagram may be developed as follows:



E_s = Sending end voltage
I = Line current
E_R = Receiving end voltage
$\text{Cos}\ \theta$ = Power factor
R^* = Resistance of the circuit per mile
X^* = Reactance of the circuit per mile

From this vector diagram the equation for the receiving end voltage can be written as follows for one mile of line.

$$E_R = \sqrt{(E_s - RI\cos\theta - XI\sin\theta)^2 + (RI\sin\theta - XI\cos\theta)^2}$$

If the quadrature components of the voltage drop are neglected, the errors introduced in the calculations of E_R for the wire sizes on REA lines and the power factors at which they operate, should be less than one percent. The quadrature components can therefore be neglected, and the receiving end voltage then becomes $E_R = E_S - RI\cos\theta - XI\sin\theta = E_s - I\,(R\cos\theta + X\sin\theta)$. The latter part of the equation, $I\,(R\cos\theta + X\sin\theta)$, represents the voltage drop. For single phase line $I = \dfrac{KW\,(1{,}000)}{E_R\,(PF)}$ where KW = load in kilowatts and PF = power factor of the load.

NOTE: A slight additional error is introduced in these computations by the assumption that the sending and receiving end power factors are the same.

Substituting the above value of current in the equation for voltage drop for a line S miles long results in the equation:

$$\text{Voltage drop} = \frac{1{,}000\,(KW)\,S\,(R\cos\theta + X\sin\theta)}{E_R\,(PF)} \text{ or}$$

$$\text{the percent voltage drop} = \frac{1{,}000\,(KW)\,S\,(R\cos\theta + X\sin\theta)\,100}{E_R\,(PF)\qquad E_s}$$

With an assumed maximum voltage drop of 8% at the end of the system, the average drop equals 4%, or on the average $E_R = 0.96\ E_s$. Substituting this value in the above equation and expressing the potential in kilovolts gives: $\%\ \text{voltage drop} = \frac{KW(S)\ (R\cos\theta + X\sin\theta)\ 100}{1{,}000\ (.96)\ PF\ (Kv)^2}$

To allow for ground contact resistance and differences in ground resistivity for single phase lines, an arbitrary increase of 5% is allowed in the voltage drop. This addition should more than take care of the errors caused by variations in the circuit impedance. The equation in its final form then becomes:

$$\%\ \text{voltage drop} = \frac{KW(S)\ (R\cos\theta + X\sin\theta)\ 105}{1{,}000\ (.96)\ PF\ (Kv)^2}$$

For three-phase voltage drop calculations the factor for ground contact resistance should be omitted, and the total Kw load should be divided by three to get it in terms of load per phase. Incorporating these changes in the voltage drop equation gives:

$$\%\ \text{voltage drop} = \frac{KW\ (S)\ (R\cos\theta + X\sin\theta)\ 100}{1{,}000\ (.96)\ PF\ (Kv)^2\ 3}$$

Both the single-phase and the three-phase voltage drop equations contain constants and other factors which are independent of the load and the length of line considered. Since these factors can be restricted to a limited number of values as far as REA line conditions are concerned, they can be grouped together in what we term a "wire factor." Wire factor values may then be calculated for the various combinations of voltage, power factor and wire size likely to be encountered on REA lines.

These wire factor equations are:

$$\text{Wire Factor} = \frac{(R\cos\theta + X\sin\theta)\ 105}{(.96)\ PF\ (Kv)^2} \text{ for single phase lines}$$

$$\text{and Wire Factor} = \frac{(R\cos\theta + X\sin\theta)\ 100}{(.96)\ PF\ (Kv)^2\ 3} \text{ for three phase lines.}$$

* These values of resistance and reactance per circuit mile have been calculated for single and three phase multi-grounded neutral lines for the types and sizes of conductors commonly used on REA-financed systems. These impedance values are presented in Technical Standards Bulletin #4 entitled "Procedure for Making a Sectionalizing Study on Rural Electric Systems," by Bruce O. Watkins assisted by Donnan E. Basler and James R. Oberholtzer, published by the Rural Electrification Administration of the U. S. Department of Agriculture.